

Lean Architecture: Toyota Home Project

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Introduction

The manufacturing industry has shifted from an antiquated Fordist model of mass production to a method of mass customization. The translation to architecture has primarily resulted in formal studies utilizing digital design and manufacturing. This over exuberant focus on the product – the technology and the things the technology can make as physical objects – rather than on the process – the social and organizational aspects of prefabrication -- has resulted in furthering architecture's irrelevance in the construction industry.



Fig. 1. Pre-manufactured "mobile" house in Arizona.

It is not that prefabrication in housing has not been successful. On the contrary, it has made great strides in the manufactured and mobile home markets, but its ability to also be architecture is the basis of the conflict. Collin Davies has written, "The strength of the prefabricated house lies in its popularity, its cheapness and the industrial based from which

it operates. These are precisely the areas in which modern architecture is weakest." He continues, "The prefabricated house...challenges architecture's most deep-seated prejudices...If architecture could adapt itself to (market) conditions and succeed in prefabricated housing business, then it might revoke some of the influence it has lost in the last 30 years and begin to make a real difference to the quality of the built environment."ⁱ Prefabrication then requires a concerted effort for architects to not only innovate in the areas of formal manipulation and image production, but also in the area of social and organizational structures that define the design and production process. Finding a balance between process (people/organization) and product (object/technology) is both the challenge and opportunity of prefabrication in architecture.

"Lean Thinking"ⁱⁱ is a methodology of business that replaces the traditional push model to a pull model, allowing the forces of a project to pull the process along. Businesses outside of architecture who have adopted the lean process have reported increases in both quality and production. One company has become the poster child for this transformation to lean production, the Toyota Motor Company, who recently has applied its principles of manufacturing toward the production of prefabricated housing in Japan. This paper will explain the Toyota Production System and the new Toyota Home Project. By evaluating this example, the culture of architecture may move closer to being able to break free from formal investigation and begin focusing on agility and customer-centric customization in a new lean architecture paradigm.



Fig. 2. Photo of drawing by Conrad Wachsmann of the Packed House.

Japanese Prefabricated Housing

Even though the United States dominates 26% of the global prefabrication housing market, Japan is the fastest growing prefabrication economy.ⁱⁱⁱ In 2004, a total of 1,160,083 houses were newly built in Japan. Among them, 159,224 houses were prefabricated.^{iv} This translates into roughly one out of every 7 new homes in Japan in 2004 were built using factory-based methods. This number has undoubtedly increased in the last 4 years. Most prefabricators in Japan use the modular method or a “skeleton infill” approach. Architects from around the world are experimenting with different types of prefabricated systems; however, gaining a significant market share by creating an efficient method for construction and manufacturing of architecture has been overlooked in favor of formal studies. Looking at historical examples of prefabrication that have failed, including architects

Gropius/Wachsmann (Fig. 2), Le Corbusier, Wright, and Prouvé to name a few, is convincing evidence that intention and image is not enough for ideas to move past the drawing board.^v Much more is needed in the future in order to take advantage of prefabrication and make it work for architecture.

Although the reason for demand differs throughout the world, there are still basic principals that draw one to prefabricated housing. Prefabricated housing theoretically is an excellent method for reducing labor and material costs, capturing large amounts of construction waste, reducing site disruption, increasing the speed of construction, and most importantly improving the quality of the end product. These are all problems that ail the traditional in situ construction system.^{vi} In addition, the growing need for affordable housing presents an opportunity for designers and builders to leverage the factory house for social equity. However, the prefabricated architectural housing process has yet to yield a truly cost-efficient system, most of the time making this option much more expensive than a standard built home.^{vii}

According to the “Government Housing Loan Corporation in Japan, the construction cost of a conventional home was estimated at 175,404 yen (US \$1,698) per square meter. A prefabricated home was at 190,033 yen (US \$1,840) per square meter,” making the reality of affordable prefabricated housing much more in the reach in Japan when compared with other parts of the developed world.^{viii} Japan also has a scarcity of land upon which to build, yet the need for housing continues to grow. Out of the approximately 49.5 million homes in Japan, only 2.2 million are of pre-war construction. Half of the wood-framed homes will have only a 33-year life span. The need for new, more efficient and durable homes is causing Japanese consumers to buy an existing home, level it, and build new. Yet, frustrations with poor construction and scheduling in the traditional method have driven many consumers to explore prefabrication as an option.

A group known as the “Big 5” currently dominate the factory-built home industry in Japan. The companies, including Shiga Prefecture, Sekisui Heim, Sekisui House, Daiwa, and Misawa, offer varying products with equally diverse methods of manufacturing.

Recently, however, there is a new rising star in the industry that is backed by a very well known expert in manufacturing, Toyota Home. Although prefabricating housing since the 1970s, Toyota recently made a concerted effort, announcing on Jan. 1, 2004 that it established a new branch to begin full-scale production of factory-built homes. That year Toyota Home built 4,700 homes. Each year since, Toyota has increased its production and has a goal to reach 7,000 units a year by 2010.^{ix} The company has transitioned its process into the home market by utilizing their world-renowned technique of lean manufacturing.

Toyota Home

become synonymous with efficient business practices as found in "Lean Thinking".^{xi} Toyota Home saw the housing industry as no exception to the principles of lean thinking. Toyota has taken 5 of its 14 principles used in auto manufacturing and applied them to the prefabricated housing market. The basic tenants include:

Just-In-Time

Jidoka

Heijunka

Standard Work

Kaizen

Just-In-Time

Just-In-Time is the backbone of lean manufacturing. Each portion of the process arrives just as it is needed to complete the final product. As a modular construction system, Toyota Homes factory production is broken into a process of materials, assemblies, components, and finally modules. Raw material inventory is built into assemblies, usually at the scale in which it can easily be moved and inventoried. Collections of finished assemblies are then pieced together to form the larger building components such as walls, roofs and floors. The basic structure or "skeleton" of the modules is erected with all the hardware installed in preparation for future wall, roof, or floor "in-fill" portions. Each of these modules are assembled and prepared by automated machines and teams. The process of teams assembling larger components into the frame to make the module is called cellular manufacturing. (Fig. 4)

Upon completion of the individual modules, they are transported to the building site and assembled as a whole house. "As a result of putting all of the trades on an assembly line, building the modules that make up a house complete with doors, windows, drywall, electrical, plumbing, and so on these modules (welded steel frame boxes finished as rooms)"^{xii} are 85% complete when they are delivered to the construction site. Each of these modules is completed in about 8 hours.

Fig. 3. Automobile manufacturing plant in East Asia.

Toyota's innovation of the lean manufacturing process began shortly after the Second World War. Many of Japan's industrialists were impressed by America's speed in which they could build aircraft and vehicles utilizing the Fordist mass production model of automation, assembly line, and economies of scale. Taiichi Ohno and Shigeo Shingo of Toyota incorporated the Ford production process with a variety of customized techniques unique to Japanese culture. In starting anew with these processes, they could evaluate the shortcomings of the Ford model, with a new critical eye and develop their own process known as the "Toyota Production System" or TPS.^x This system has been highly praised and received awards around the globe for its focus on people through mass customization and utilization of economies of scope. Several industries, other than the automotive sector, have been using this production model as a basis in which to ground their own practice. (Fig. 3) TPS and lean manufacturing have

Toyota is always trying to improve its system of manufacturing. As an example of finding more efficiency in the Just-In-Time delivery, Toyota has recently moved their window manufacturer into their production facility making schedule, cost and quality more predictable.

space where everything the employee or machine needs is within arm's reach and in the exact quantity needed. (4) Waiting: This is one of the largest obstacles in the production process: waiting because a process is not completed, prints are not ready, machines or tools are not working. Also, workers need to be motivated and work at a consistent pace. These ideals are described in later sections Jidoka and Kaizen. (5) Processing: This is defined as processes that make no impact in the viewpoint of the customer. This can amount to wasted time cleaning workspace, large quantities of paperwork, etc. Design of the process and the way that it is carried out remedies counter-productive process conflicts. (6) Inventory: Stock only what the customer needs. A healthy relationship with suppliers or even producing a majority of parts in house can reduce cost significantly by eliminating inventory overhead. (7) Defects: Imperfections or missing parts can double the time for a simple task. Inventory on-hand should be inspected and controlled to simplify work processes.^{xii}

Jidoka

Jidoka is automation with a close human element. Toyota's approach is to use automation only when the human task has been perfected and deemed to have no handcraft value. By studying the perfected technique that has been removed of all its waste, the automation can take over without having to go through the costly research and development stages to eliminate waste. Toyota also believes that the machine should never replace the worker, but work along with them to manufacture a more precise quality product. Another development that is just as important as the machine's ability to produce, is its ability to stop.

If there is a defect or problem in the production line, it is beneficial that the machine halt development and fix the problem so that no additional inventory is wasted or assembly is damaged. Jidoka is a necessity in the prefabrication housing market in order to bring down production cost and improve overall quality. According to a survey performed by the Japan Prefabricated Construction Suppliers and Manufacturers Association, 23% of Japanese homeowners would strongly consider purchasing a prefabricated home. The primary reason for their interest was due to the perceived high level of quality. Jidoka allows Toyota to achieve

Fig. 4. Module fabrication at Toyota Home factory in Japan. Photo Credits: Katsumi Kasahara, AP

Toyota's lean manufacturing approach has made itself unique by diligently finding ways to reduce waste and increase efficiency. Taiichi Onco described 7 waste or "Muda" that required immediate elimination and constant refinement in its production of housing. (1) Over production: Units need to be built on demand. Stocking up inventory provides fluctuations in production speeds that waste space and employee power. Each Toyota Home is built to order. (2) Transportation: Much time and space is wasted when there are huge stock piles of inventory placed too far from the production zone. Manufacturing lines must be arranged so that when a process is finished, it is located in a spot that will continue it on its way. (3) Motion: Workspaces need to be clean and organized with the flow of assembly. Toyota's cellular manufacturing sets up such a

higher construction tolerances on a regular basis, waste less material, assemble more smoothly without devising methods to fill in gaps or mend broken parts, and shorten the schedule for construction. Also the divide between the digital design and CNC manufacturing process can be reduced because components and connections can be designed knowing that they will be produced exactly as they have been tested.^{xiv}

Heijunka

Heijunka is the system by which Toyota Home keeps inventory low and in constant supply. Toyota accomplishes this by manufacturing directly to customer order. Standard work allows for Toyota Home to keep a well-stocked supply of raw materials. The future owner of a home will go to the Toyota home park where they may browse many of the options and select specifics. The Toyota home website allows patrons to virtually apply a variety of claddings, colors, exterior/interior ornament in a customizable environment to suit their needs and tastes. All of these options are based on the same raw materials kept in stock so when the order is issued, they can be pulled off the shelves and go through the process of assembly to component to module to whole house erection on site.^{xv}

The principles of Heijunka have been manifest in many industries as an emerging customer-centric enterprise. Giving individuals the ability to customize facilitates both customer predictability and product variety. Toyota offers vehicles with many customizable features. The most notable is the Scion that can be ordered with features usually only available from third party shops, but Toyota offers them as free options or cost added upgrades.^{xvi} Puma has started a similar campaign with customer designed shoes using an interactive website. Shoes are in a predetermined form and construction, but the materials and pieces that make up the shoe are selected from an array of available choices. Consumers are able to "design" their own shoe for a small increase in cost.^{xvii}

Standard Work

Not all of the elements that are compiled to make the Toyota Home modules and finally the completed structure are customized. From the decades of producing automobiles, Toyota

understands the principles of utilizing standard components and systems make the drive towards efficiency much simpler. Each year a handful of car models are produced, many of which are modifications of the previous years' production. A basic model with minor modifications over several years allows Toyota to understand the core structure of the automobile, and thereby produce the part with greater effectiveness and reduced cost. Therefore, the modules are standardized with customization built into the configuration and relationships between modules.

The Toyota Home models: Vietrois, Smart Stage, and Espacio Mezzo are made unique by the modules that make up the final house. There are 12 modules to a home, depending on the size requested by the owner. The modules themselves are built with a steel frame that can be easily adapted to the often-varying lengths of modules. Each of the modules' steel frames is specifically designed for Japan's seismic activity. A regular home has a system of exterior enclosure walls, roof and floor panels that define space, while outside flexible steel frame provide a frame work. When the Toyota's modules are locked together, the structural frames of the modules in tandem create a rigid structure. The spaces inside the modules may be delineated by interior partition walls or may be defined as needed.

Even with the flexibility and the multitude of configurations, Toyota Homes are still based on a simple set of standard rules on assembly. This allows Toyota Home to have tested the efficiency of the systems installed. For instance, when the modules are constructed, a simple path is designated to allow air to be pulled easily from the lower levels through the roof. Along these paths, special air filters turn on if they detect too high of formaldehyde or CO₂ content, tobacco odor, or pollen. This proven system of precisely controlling air movement through the home has caused Toyota's homes to have 30% cleaner indoor air than the recommended value by the Japan Building Standards Law.

In addition to the modules, miscellaneous materials for the homes installed on site are manufactured in the factory in order to ensure the same level of tolerances across all of its fields. Approximately 80% of the Toyota Home plant is computer controlled to allow for the only the slightest variation between parts. Technology unique to Toyota is shared

between the motor and housing branch. For example, the smart key system used on the Prius hybrid car is also used on the home so the front door recognizes when the owner is near and unlocks and locks the door when he/she is coming or going. The same scratch resistant technology for the automobiles is used on the interior and exterior walls. Engine mount isolators that are used to create a smoother, quieter ride are used between steel and floor decking to minimize noise transfer from floor to floor, a common problem with most residential construction.^{xviii}

Standard work allows the manufacturer and consumer to be extremely confident that the product they produce and receive will be of the utmost practiced quality. Toyota's confidence is expressed in offering a guarantee of up to 60 years on the life of the prefabricated house.

Kaizen

Kaizen is the human element of lean manufacturing. The production line technicians are asked to begin each day as if it were the worst day, developing a critical awareness to recognize and solve problems. Kaizen asks employees to find solutions as a team, focusing on a series of small tested solutions rather than a macro level fix-all solution. Toyota Home employs the entire staff of design and production including architects, engineers, manufactures, machinists, and computer scientists. The diverse fields act as a team to produce a quality product efficiently. If a problem arises anywhere in the process, it is easy to bring in representatives from each of the disciplines. Those who design and those who fabricate work on the same level and collaborate with their unique tasks to find a worthwhile solution. The lack of hierarchy and emphasis on communication and problem solving allows the prefabrication process to move quickly and efficiently.

Kaizen is a substantial contrast to the American system of project delivery. Architecture, Engineering and Construction in the U.S. is laden with a litigious culture that hinders collaboration, innovation and progress. Often the individual or group that is most affected by this adversarial relationship is the owner. Bringing the parties together as one entity breaks down the cultural and contractual barriers that slow the construction process in the U.S. Kaizen allows a level, open playing field that welcomes continual criticism and

leads to continual refinement of both product and process.

Fig. 5. Rendering of one of Toyota customizable home designs (www.toyota.com)

Lean Architecture

Now and in the near future, designing and building demands that architects facilitate an integrated delivery process. For prefabrication to thrive, increased sharing, trust, as well as development and use of technologically advanced materials and information technology tools are necessary. As opposed to the master builder who was the material scientist and constructor, or the 20th century architect that has limited, if any, connection to the process of material and building progress, the 21st century architects have the opportunity to situate themselves as key players who develop an integrated collaborative in a design and building project. It is precisely the process of collaboration in which innovation can be fostered and thrives.

"Commodity, most believe, is the creed of the philistine. It is possible, however, to see commodity instead as the crucible of arts itself and to recognize the process engineer – not the design engineer – as the high priest of this new art."^{xix}

Ironically, in all the discussion regarding prefabrication, a focus on people and process and not product appears to be the fastest way to realizing this ideal in design and building.

Outside of material and digital technology itself, the environmental, organizational and social barriers to collaboration and consequently innovation include a lack of culture of

collaboration, an outmoded construction handi-craft method of building, and a litigious risk adverse practice. Overcoming these challenges, Toyota uses the five techniques discussed above including: Just-In-Time, Jidoka, Heijunka, Standard Work, and Kaizen. These principles allow Toyota Home to transfer their proven success in the automotive industry to prefabricated housing. Using these techniques, they have been able to succeed where many other architects and companies around the world have failed.

Even with all of the impressive advances Toyota Home has made in efficiency and constructible modularity, a question still remains: Is the Toyota Home architecture, prefabrication, or both? (Fig.5) Although the Toyota Homes are not aesthetically remarkable, they exhibit a range of possibilities when design and manufacturing collaborate to produce a single refined product. With the architecture developing into a model integrated practice, sustainable green building and prefabricated housing, arguably the questions of the 21st century have much less do with what we build but how we build it. Toyota Homes design and construction provides architects, engineers, and manufacturers with a case study in the organizational practices of how to design and deliver quality-prefabricated housing.

Notes

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